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Spacecraft Instrumentation to Measure and Stimulate Space Particles and Plasma Waves in the Medium-Earth Orbit (MEO) Regime

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14. ABSTRACT

UCLA is building a three-axis fluxgate magnetometer for the AFRL-DSX mission. The instrument is designed to measure the medium-Earth orbit geomagnetic field with precision of 0.1 nT and provide the field direction to within 1 degree. The instrument will provide the DC magnetic field for phase space density calculations of energetic particles, the magnetic field vector information for the Loss Cone Imager (LCI) payload, and the ULF wave environment. The project is on schedule for engineering delivery in October 2006 and flight unit delivery in October 2007.

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1. INTRODUCTION

This effort is in response to the Battlespace Environment Division, Space Vehicle Directorate, Air Force Research Laboratory's (AFRL) call to develop and provide a vector fluxgate magnetometer to support both the Space Weather (SWx) and Radiation Belt Remediation (RBR) payloads on the Demonstration and Science Experiment (DSX) which will be launched into the Medium-Earth Orbit Space Environment Regime.

Included as part of the DSX payload is a vector magnetometer. The vector magnetometer provides measurements of the terrestrial field, which is essential to fulfill the two primary goals of the DSX science program. The fluxgate magnetometer provides the necessary data to support both the Space Weather (SWx) specification and mapping requirements and the Radiation Belt Remediation requirements. The magnetic field is necessary to reconstruct pitch-angle distributions (PADs), to calculate phase space densities, and to determine important local plasma parameters such as plasma beta and the local index of refraction. The fluxgate magnetometer provides measurements of the magnetic fields caused by currents that flow into and above the Earth's ionosphere. These currents close with currents in the Earth's magnetosphere, via field-aligned currents, and measuring these currents is essential for improvements in magnetospheric specification models.

This annual report describes UCLA's first year effort (April 2005 – March 2006) in designing the vector magnetometer for the DSX program. This magnetometer is based on the fluxgate design that has been developed over the years by UCLA. We have developed a magnetometer that easily conforms to the DSX requirements (as specified in L0/L1 Requirements Document and Common Requirements Document Rev D), with a high degree of reliability and a low impact on spacecraft resources in terms of mass, power, and volume.

The Annual Report is organized in the following way. After discussion of the scientific rationale and heritage of the UCLA magnetometer design, the report will discuss the specific work done during the first year of this project. Specifically, the report will summarize the mechanical and electrical design and interfaces, materials, parts, documents, Integration and Test, and analyses performed to verify the design. Much of this discussion will be brief. The reader is referred to the Preliminary Design Review and Critical Design Review documentation submitted to the DSX Project Management Office as part of the regular reporting process.

1.1. Scientific Rationale: Ring Current and ULF Waves

As an educational institution, UCLA's primary motivation in providing fluxgate magnetometers for DSX is directed to the scientific return from the mission. Improving our scientific understanding often goes hand-in-hand with improving the technology of our scientific instrumentation. Hence, UCLA's strong interest over the years in continuing to develop science-grade magnetometers. The DSX mission clearly benefits from this extensive heritage in scientific instrumentation. Moreover, that UCLA's effort will contribute to the operational goals of DSX which allows UCLA to provide an immediate societal benefit. This return of investment for the nation is also important for UCLA, allowing us to show the value in conducting basic research.

The magnetometer is essential for fully characterizing the particle and wave data to meet the Space Weather and Radiation Belt Remediation goals. However, in addition to the supporting role of the magnetometer, the data provided by the instrument will clearly be a valuable resource for the Space Physics Community on its own. At UCLA, our scientific efforts are centered around the observations of magnetic fields due to current systems in the Earth's ionosphere and magnetosphere and to the ULF wave environment.

There have been very few spacecraft with research-quality vector magnetometers flown in MEO orbits. Therefore, the DSX mission will be ground-breaking in terms of providing information about the Earth's geomagnetic field and ULF wave environment in the inner magnetosphere. Depending on the orbital inclination of the spacecraft, a wide variety of science objectives can be addressed. The science objectives outlined in this proposal assumes the nominal 30° inclination described in the solicitation (AFRL/VSB04-01).

The MEO magnetospheric regime has not been extensively studied because most scientific satellites are either in LEO-Low Earth Orbit (e.g., SAMPEX), HEO-highly elliptical orbit (e.g., SCATHA, AMPTEE, ISEE 1/2), or at GEO-Geosynchronous orbit (e.g., GEOS 2, the LANL spacecraft). MEO orbit covers a range of interesting space physics regimes including the radiation belts (Figure 1), the ring current, and the plasmasphere and is home to a growing number of satellites (such as GPS) so understanding the MEO space weather environment is becoming more and more important [e.g., *Le and Russell,* 1993].

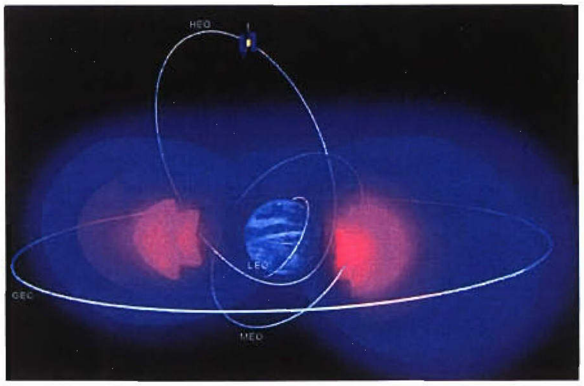

Figure 1. The Van Allen radiation belts and typical satellite orbits. Key: GEO — geosynchronous orbit; HEO — highly elliptical orbit; MEO — medium Earth orbit; LEO — low Earth orbit. (Illustration by B. Jones, P. Fuqua, J. Barrie, The Aerospace Corporation.)

The specific region of the magnetosphere to be explored by the DSX satellite between 10,000 and 20,000 km altitude (*L* between 1.5 to 3.1) is now known to be an extremely dynamic region overlapping the radiation belt slot (Figure 2), a region where the plasmapause often resides (Figure 3), and a place of intense wave activity (Figure 4) [e.g., *Baker et al.,* 1994, *Moldwin et al.,* 2002, *Bortnik et al.,* 2003, *O'Brien et al.,* 2003].

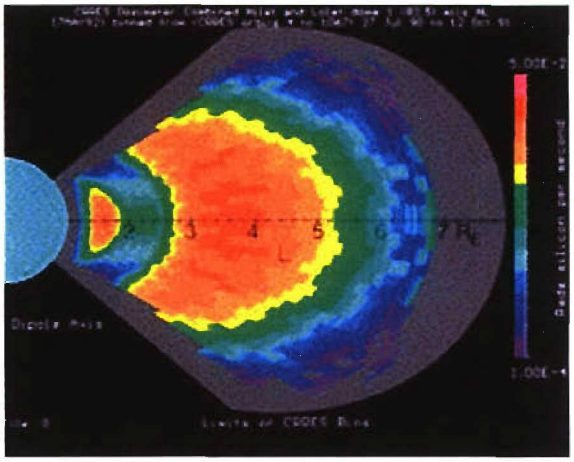

Figure 2. The intensity of the inner and outer radiation belts as observed by CRRES. The DSX satellite will have an orbit between 1.5 and 3.1 *L*, spanning the inner belt, the slot, and the inner edge of the outer belt.

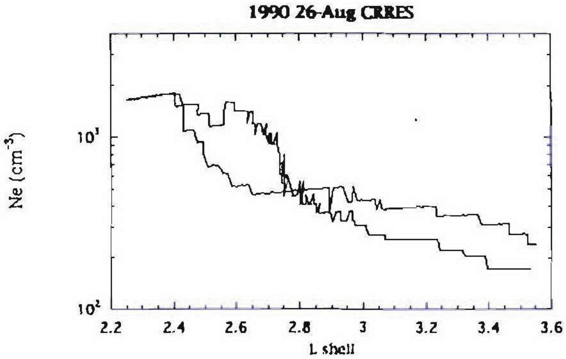

Figure 3. CRRES plasma density data for an inbound and outbound orbit showing the plasmapause and density structure between *L* of 2.5 and 3.

In addition, DSX will provide the study of ring current dynamics and field-aligned currents (FAC) from a unique perspective deep in the inner magnetosphere. Two specific

questions to be addressed by DSX are (1) what is the ULF wave environment in the inner magnetosphere during severe geomagnetic storms? And (2) what is the configuration of the inner magnetospheric magnetic field during storms? With one satellite it is difficult to place the observations into global context – however, UCLA operates three mid-latitude magnetometer chains (MEASURE, SAMBA, and McMac) that span the DSX L shells and can be used to estimate the inner magnetospheric mass density, independently estimate the location of the plasmapause, and characterize the global ULF wave environment. The PI on this proposal is the PI on MEASURE and a co-PI on SAMBA and McMac.

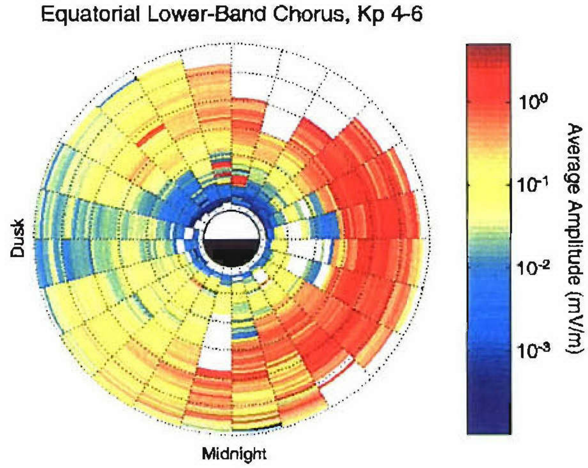

Figure 4. Average equatorial lower-band chorus amplitudes for Kp 4–6, observed by CRRES [from *O'Brien et al.*, 2003].

These complementary ground-based datasets will be used in addressing both questions. Specifically for question (1), we will compile a database of ULF wave power as a function of LT, Magnetic latitude, L shell, and geomagnetic activity (as indicated by Dst, Asym, SymH, Kp, and AE) by automatically calculating dynamic power spectra. The result will be similar to the survey of AMPTE data by *Anderson et al.* [1990], but will cover the inner magnetospheric region.

For question (2), a satellite in a 10,000 x 20,000 elliptical orbit would have a orbital period of about 3 hours and 20 minutes. This is comparable to the time scale of the main phase of a geomagnetic storm. Therefore DSX will sample a range of local times during the main phase of each storm allowing for the examination of the evolution of the partial ring current for a variety of storms. Recent studies have shown that the inner magnetosphere can be severely distorted during geomagnetic storms due to the growth of the partial ring current [e.g., *Tsyganenko et al.*, 2003].

2. MAGNETOMETER HERITAGE

The UCLA fluxgate magnetometer has been employed in state-of-the-art investigations of magnetospheric and solar system magnetic fields for over 35 years. During this time the accuracy and precision of the magnetometer has grown even as its mass, size and power decreased. In this section we review the heritage upon which the UCLA ST5 design rests.

2.1. The Early Years: ATS, OGO 5, Apollo and PVO

UCLA has a long history of supplying science-grade magnetometers, as shown in Figure 5. The UCLA magnetometry group was established in the mid 1960s by P. J. Coleman when it furnished fluxgate magnetometers for ATS 1 and 6, and OGO 5. The ATS 1 instrument was a simple, spinning, two-axis instrument, very much in the spirit of "better, faster, cheaper" and innovative for its time. ATS 6 was a three-axis, inertially stabilized measurement. The OGO 5 magnetometer was the first magnetometer capable of accurately measuring both the full Earth's field and the smallest (interplanetary) magnetic fields in the neighborhood of Earth. It accomplished this with a ladder-adder network, basically a high-resolution A/D converter in which the basic magnetometer was embedded. While it was successful in many respects, it was very

complex and calibration was time consuming. In 1971 and 1972 the Apollo 15 and 16 sub-satellites carried UCLA fluxgate magnetometers of a very simple design in a low field environment. In 1972 and 1973 UCLA was selected to build both the ISEE 1 and 2 fluxgate magnetometers as well as the Pioneer Venus orbiter magnetometer. Both presented challenging design issues but quite different ones. The ISEE magnetometer required a very precise measurement of a mag netic field whose strength varied from 5 nT to over 8000 nT. UCLA built a highly linear magnetometer with two gain states with a 12-bit A/D converter accurate to LSB. Oversampling and averaging provided 14-bit accuracy and 16-bit resolution. The richness of the scientific return from this instrument attests to the success of this approach. The Pioneer Venus spacecraft was a spinner whose data rate at times was insufficient to return even a vector-per-spin period. We developed a Walsh-Transform-based despinner to provide accurate vector information under all telemetry rates. The ISEE 1 and 2 spacecraft lasted 10 years and the Pioneer Venus mission lasted 14 years. The offsets and gain factors remained stable throughout the mission. All three magnetometers were still operating upon entry into the atmosphere.

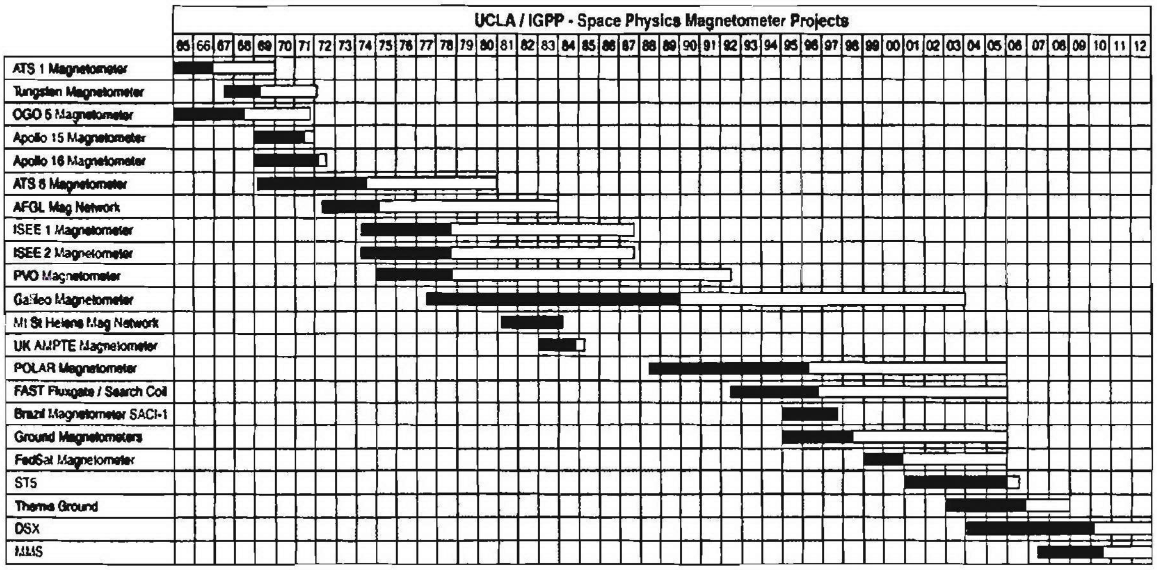

Figure 5. Spaceflight and ground-based magnetometer programs at UCLA over the last 35 years summarize the accomplishments of the group. Dark bars show fabrication and light bars show operational phases.

2.2. Galileo

The innovation of the UCLA magnetometer group continued with development of the Galileo fluxgate magnetometer. This magnetometer with a 12-bit radiation hardened A/D converter with LSB accuracy again provided 16-bit resolution data through oversampling and averaging. In addition, it stored and returned despun average data between telemetry sessions so there could be total orbital coverage. This instrument launched in 1989 was still functioning normally after 14 years in space, much of which was in a very harsh radiation environment, when the spacecraft was intentionally plunged into Jupiter in September 2003.

2.3. Polar

The Polar magnetometer launched in February 1996 is a highly accurate magnetometer with further advances in low noise and linear-

ity. Polar has a 16-bit A/D converter and can amplify the signal by another factor of 8 so the basic magnetometer was designed to 19-bit precision in order to match its A/D accuracy. The magnetometer was accurate to within 0.01%. The success of this approach can be seen in the quality of the published results and the open access provided to all the data including the highest sampling rate data. These data can be accessed over the worldwide web at http://www-ssc.igpp.ucla.edu/forms/polar.

The Polar magnetometer included both an inboard and outboard magnetometer, each with two gain states to allow for measurements at perigee (2 Earth radii geocentric distance) and apogee (9 Earth radii). The Polar magnetometer was designed to sample data at 100 Hz, and with on-board averaging to obtain lower data rates. Two other magnetometers, that on FAST launched in August 1996, and that on FedSat launched in 2002, are simplified derivatives of the Polar design.

2.4. FAST

The FAST magnetometer, with a 64,000 nT range and 2 nT resolution, was designed to operate at low altitudes (< 4000 km altitude) with ambient fields ranging from 10,000 to 50,000 nT in magnitude. The FAST instrument could acquire data at a variety of rates, up to 512 Hz. This instrument, which is still acquiring data after seven years of on orbit operations, formed the basis of the FedSat and ST5 designs. The FAST magnetometer demonstrated UCLA's ability to build highly reliable magnetometers with low noise levels, low non-linearities and stable (i.e., well behaved) offsets and gains for "full-field" operations.

2.5. FedSat

The FedSat magnetometer uses the highly successful Polar design with techniques to reduce mass and power developed on the FAST program and our ground-based effort. Figure 6 shows the FedSat engineering unit. The magnetometer has a 60,000 nT range and is sampled at either 10 or 100 Hz. The analog board weighs 200 g. A similar (analog only) instrument was fabricated and launched in September 1999 on the Brazilian SACI-1 micro-satellite but for unknown reasons no telemetry was received from the spacecraft despite a successful boost into orbit. Table 1 shows that mass of the basic UCLA magnetometer continued to shrink even as it grew more precise and accurate.

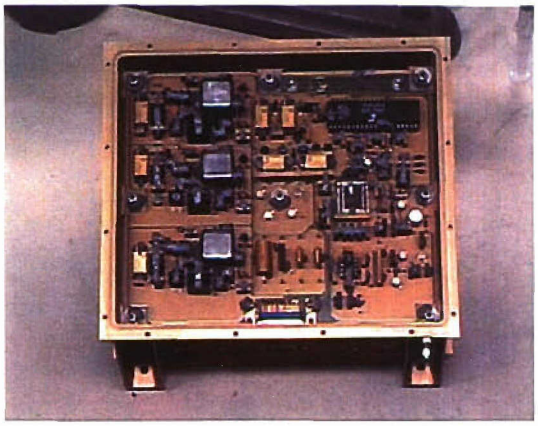

Figure 6. FedSat engineering unit showing electronics board and chassis.

Table 1. Modern Components and Continued Improvements Have Lowered the Mass of the UCLA Basic Circuitry.

Mission Name	Ranges [nT]	Cadence [Hz]	Mass [g]	Area [cm^2]
ISEE	8000, 556	4, 16	500	650
Galileo	16,000, 512, 32	0.05, 3, 32	500	650
Polar	47,000, 5700, 700	8.3, 100	400	450
FAST	64,000	Up to 512	350	400
FedSat	60,000	10,100	200	240

2.6 Ground-Based Magnetometers

Deployment of UCLA's precision, low-cost, ground-based magnetometer for studying ionospheric and magnetospheric currents was a very important development in magnetometry at UCLA. This magnetometer can

measure less than 0.1 nT in the full Earth's field with precision GPS timing control and costs less than $6000 to build. It is built on a PC board and installed in a PC chassis. The PC provides the power and accumulates the data. The circuit board is shown in Figure 7. UCLA has built and installed over 30 of these devices building ten at a time and testing them five at a time at its San Gabriel test site. These magnetometers are now operating from the Canadian arctic to the equator.

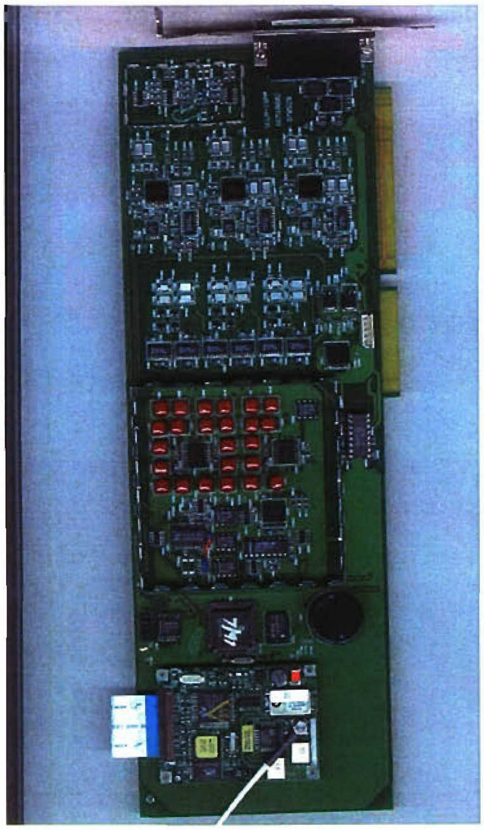

Figure 7. The circuit board of the ground-based magnetometer illustrates that UCLA has proficiency in surface mount technology.

This effort enabled the UCLA team to become proficient in surface mount design and fabrication techniques. These techniques allowed the Polar design to be implemented on an 11 cm x 25 cm board, which is one quarter the board space originally used on Polar. For the ST5 technology demonstration project, we are using the same technology with an even simpler design to achieve a further reduction in board space.

3. MAGNETOMETER DESIGN

The DSX magnetometer design is based on that used for ST5, and we describe the development effort for the ST5 magnetometer in some detail (see also UCLA's ST5 website http://www-ssc.igpp.ucla.edu/st5). UCLA's ST5 fluxgate magnetometer is the product of a long series of successful spaceflight magnetometers. The sensors are boom mounted and have no active components. Drive, sense and feedback signals travel along the boom cable between the sensors and the electronics board on the spacecraft. The electronics whose functional block diagram is shown in Figure 8 generates the fluxgate drive signal, detects the second harmonic of this signal, nulls the field surrounding the sensor, and provides a digital reading of the current needed to null each of the sensors. This signal is then sent to the telemetry system. There is no microprocessor in this simple design.

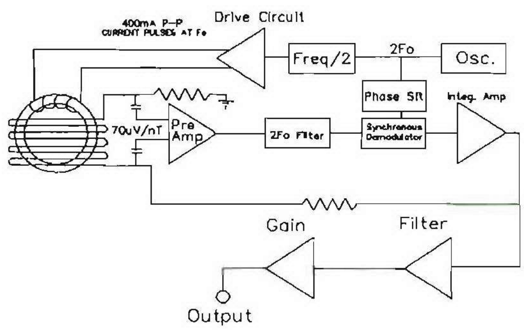

Figure 8. The functional block diagram of the UCLA ST5 fluxgate magnetometer showing its drive, sense and feedback circuits.

3.1. Fluxgate Sensors

A fluxgate magnetometer is the best choice for the ST5 and DSX objectives because of its extensive heritage on space missions and superiority to other magnetometer types. By way of comparison, we have examined other devices in our laboratory such as the new Hall Probe chips and the gross magnetoresistive resistor (GMR) magnetometers. These devices have little or no flight history, and have noise and offset stability performances that are several orders of magnitude higher than that required for either the DSX or ST5 projects.

The fluxgate sensors in the UCLA magnetometer are manufactured using the latest low-noise ring-core technology. The ring bobbin is machined from Inconel X-750. The magnetic material wound on the bobbins is low-noise 1/2-mil-thick 6-81.3 Mo-Permalloy. This material was first developed at Naval Ordnance Laboratory, White Oak, in 1986, by *Gordon, Lundsten, Chiarodo and Helms* [1986].

Figure 9. The 3-axis ring-core fluxgate sensor fabricated by UCLA for ST5. A similar design will be used for DSX. The DSX sensor will occupy a volume of 5x5x5 cm.

UCLA purchased the last of the ring-core material in 1998 and had it fabricated into small (3/8" and 5/8") cores in anticipation of future missions. The sensors are similar to our standard design flown on many previous missions. The feedback windings enclose the cores so that in operation the cores themselves are never exposed to strong fields orthogonal to the sense axis that can cause distortions at the level of about 1 part in 10^4 [*Brauer et al.*, 1997], as found on Magsat [*Acuna*, 1981]. The lack of active components on the sensors means that they are very tolerant of temperature extremes. They were qualified at over 100C on Galileo and have operated after being immersed in liquid nitrogen (-196C). The sensors require no heaters. Because UCLA fabricates its own sensors, it has complete quality assurance control of the assembly process, leading to greater mission assurance. Figure 9 shows the sensor being fabricated for ST5. Because DSX is less mass constrained than ST5, we propose to use the same basic design with larger 1-inch cores. This increase in the mass of the sensor will result in lower noise levels.

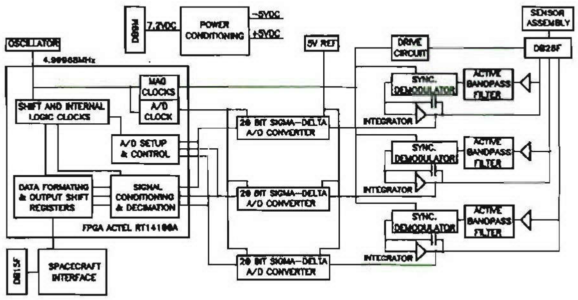

Figure 10. Basic fluxgate magnetometer circuit that has been used successfully in space by UCLA for 35 years. One of the keys to the excellent linearity, stability and noise of the UCLA implementation of this circuit is careful selection of parts.

3.2. Drive and Sense Circuits

The ST5 magnetometer uses the classic fluxgate circuit presented in Figure 10. Sensor mass and power are kept low with a dual-core series drive circuit. Thus, there is only one

drive circuit needed for ST5. This single-drive circuit was used successfully on FedSat.

As part of our development effort for ST5 we have conducted noise and non-linearity tests for the fluxgate circuits. Noise levels are shown in Figure 11, and results from the non-linearity test are shown in Figure 12.

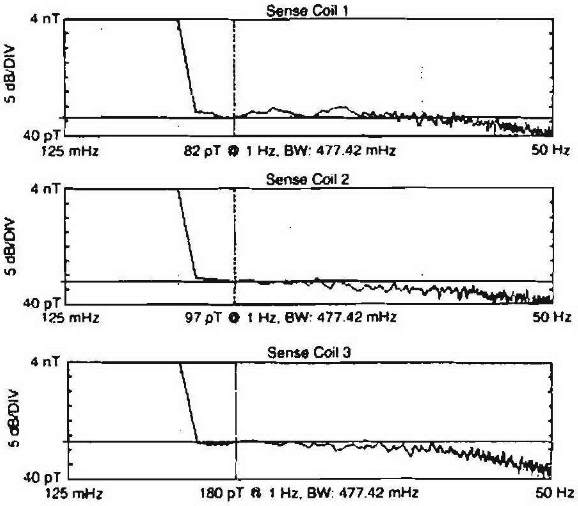

Figure 11. Noise level tests for the ST5 magnetometer.

From Figure 11, we see that the noise levels are of order 100 pT RMS at 1 Hz, with a 500 mHz bandwidth. These noise levels are clearly adequate for the DSX mission requirements. Moreover, the measured non-linearities are well within DSX requirements.

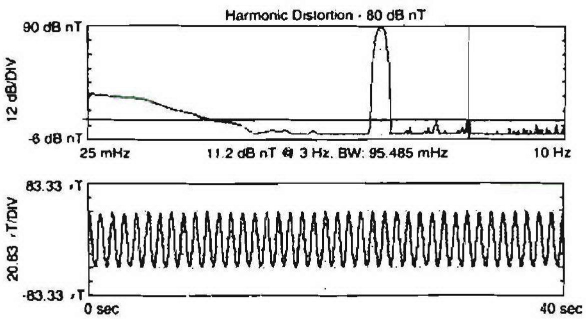

Figure 12. Non-linearity tests for the ST5 magnetometer. The magnetometer is excited with a 1-Hz tone. Harmonic distortion is below –80 dB.

3.3. Analog to Digital Converter

The specifications for the ST5 magnetometer called for 17-bit conversion of the measured fields. The AD7714 sigma-delta converter was selected and has been qualified for ST5. ST5 is scheduled for launch in 2004-2005.

Within the ST5 magnetometer, the magnetic field is sampled at 96 vectors/second. The data are then recursively filtered to provide data at 16 vectors/second to the spacecraft telemetry. This digital filtering has been a standard feature of UCLA magnetometers, as it reduces aliasing by signals above the Nyquist frequency, and also improves the noise characteristics of the magnetometer. For DSX we propose to provide a data rate of ~ 20 Hz.

3.4. ST5 Magnetometer Properties

The properties of the ST5 fluxgate magnetometer are summarized in Table 2. These are included here as the baseline from which we will derive the specifications of the DSX fluxgate magnetometer.

Table 2. Summary of ST5 Magnetometer Properties.

ST5 Mechanical Properties	
Sensor Mass	75 g
Sensor Volume	4x4x6 cm
Electronics Mass	250 g
Chassis Mass	250 g
Chassis Volume	10x12x8 cm
Interface Cable	66 g
ST5 Electrical Properties	
Sensor Power	50 mW
Electronics Power	500 mW
ST5 Characteristics	
Dynamic Range	+/- 64,000 nT
Resolution	1 in 64,000 nT 0.1 in 1000 nT
Sample Rate	16 vectors/s
Absolute Accuracy	< +/- 0.01%
Noise (0.5 Hz bandwidth)	< 0.1 nT rms
Orthogonality Knowledge	< 0.1 deg
Alignment Knowledge	< 0.1 deg

4. DSX VMAG DESIGN

The following discussion summarizes the first year's effort on the design of the DSX VMAG. Material was drawn from Data Package prepared by UCLA for the PDR and CDR. Most of this material are presented as Appendices as described below.

During the first year of this project, UCLA engineers and the PI participated in a number of DSX project meetings including the Phoenix Workshop, and All HANDS Workshop at Hanscom AFB, weekly teleconferences for the WpiX payload, teleconferences for the EMI/EMC working group, and the preliminary design review (PDR) held at UCLA. Upcoming milestones include delivery of the engineering unit in October of 2006 and the Flight Unit in October of 2007. UCLA has built and delivered an VMAG Simulator to PSI in Melbourne for ECS interface testing. This testing was successfully completed in April 2006.

4.1. Mechanical Design

The VMAG fluxgate derives heritage from long-line of UCLA magnetometers. The design will be a more rad-hard flow down from the NASA ST-5/Polar magnetometer. The sensor is shown in Figure 13 and the electronics board in Figure 14. Printed Circuit Board (PCB) is housed in aluminum and hard mounted to spacecraft.

Table 3. VMAG Physical Properties.

VMAG Mechanical Properties	(g or cm)
Sensor Mass	500
Sensor Volume	11.1x6x8
Electronics Mass	240
Chassis Mass	1360
Chassis Volume	24x14x3.2
Interface Cable	160 g/m

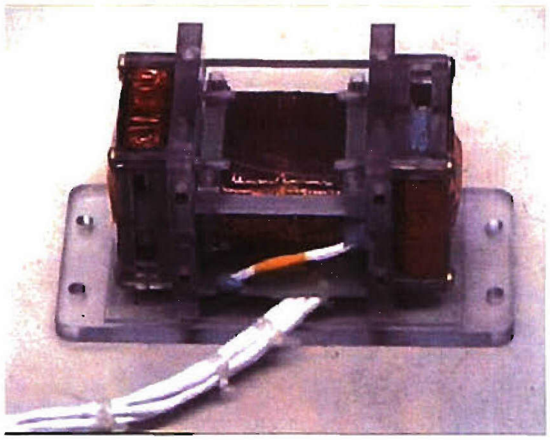

Figure 13. Sensor: 6.0 x 11.1 x 8.1 cm.

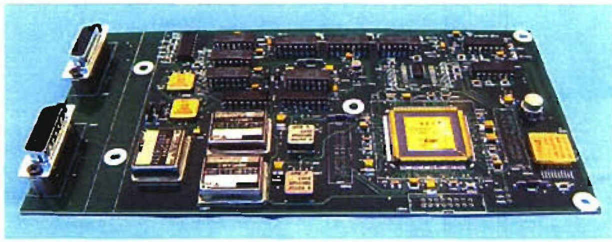

Figure 14. Development Unit: 11.4x20.32 cm.

VMAG has no moving parts.

The Mechanical Fabrication Approach is the following.

- All in-house procedures and tests involving flight instrument performed by NASA certified technicians.

- Incoming flight parts inspected, kitted and stored.

- PCB manufactured by outside contractor (Cirtech), to MIL-PRF-55110.

- PCB coupons tested and certified by independent contractor (DELSEN Labs).

- EU chassis milled to specification at Bellfx LLC

- Sensor chassis milled to specification / drawing in-house.

- PWA assembled using AIDS.

- EU and sensor chassis tested for fit, plated by outside contractor (California Technical Plating) to UCLA0280-PLT.doc, and painted in-house to UCLA0240-PNT.doc.

- Sensor and EU chassis inspected in-house.

- Sensor ring cores wound (Mercury Magnetics).

- Sensor Bobbins and armature parts machined to specification/drawing.

- Sensor ring cores, bobbins, armature parts and EU PWA will be inspected in-house

- Sensor will be assembled (except for cover) and pigtail cable will be attached to sensor.

- Sensor assembly will be inspected in-house.

- Flight and engineering model boom cables will be constructed by either UCLA or by the boom provider with UCLA supervision.

- Flight boom cable will be inspected by UCLA personnel.

- After engineering test, tuning, and qualification, PWA will be inspected in-house.

- PWA will be conformal coated and will be given final QA inspection in-house.

- PWA will be installed in EU chassis and cover will be installed on sensor assembly.

- Instrument is then ready for environmental testing and burn-in.

- The structural models were developed using SolidWorks® and submitted to the DSX PMO.

4.2. Mechanical Interface

Drill templates will be supplied for mounting the VMAG sensors and electronics unit to the spacecraft. The physical mounting location of the VMAG sensor is to be determined by the DSX and spacecraft contractors. The VMAG sensor will be boom-mounted to reduce the effects of spacecraft-induced-magnetic fields.

The sense axes of the fluxgate magnetometer do not physically align exactly with the axes of the sensor assembly. As part of the VMAG calibration, sense-axis alignment will be determined to within 0.01 degrees accuracy with respect to reference axes of the VMAG sensor assembly. See ICD for more details.

4.3. Electrical Design

The basic electrical design is described in the heritage section of this report. Details of the VMAG electrical design can be found in the CDR package and the electrical properties are give in Table 4.

Electrical power is to be supplied to VMAG at 28 VDC. VMAG includes power conversion and conditioning circuits, as well as ripple and transient protection. On-orbit experience with FAST indicates that no survival heaters are required, although thermal regulation is included for normal operations.

VMAG has one operation mode – ON.

Table 4.

VMAG Electrical Properties	
Sensor Power	50 mW
Electronics Power	1.95 W

4.4. Ground Support Equipment

The GSE is the VMAG interface that performs the following:

- Supplies Power to VMAG EU.

- Converts RS-422 serial interface from VMAG EU into formatted USB data stream.

- Monitors VMAG EU temperature and current.

- Provides access to internal VMAG test interface.

- Provides stimulus current for shield can coils and Helmholtz coil.

- Provides support for SFT, BAT and thermal vacuum/thermal cycle tests.

Deliverables include the following:

- Laptop Computer (Dell Latitude D510)

- GSE chassis

- 26 conductor cables between GSE chassis and VMAG EU (with connector savers)

- USB cable between GSE chassis and laptop.

- GSE manual

- Helmholtz coil

- Magnetic shield can (on loan to project)

- 3 BNC

- Breakout box

The GSE uses LabView® and is Ethernet capable for remote operation. Figure 15 shows the LabView® interface and Figure 16 shows the front panel of the GSE.

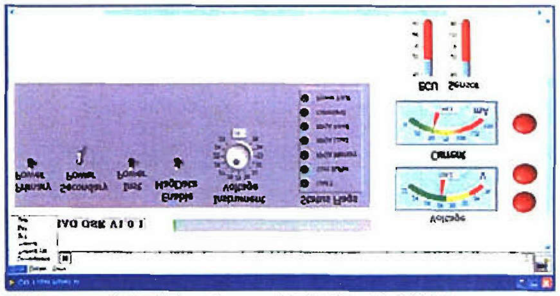

Figure 15. Display of VMAG GSE.

Figure 16. Picture of GSE Chassis.

On the basis of prior flight heritage, the VMAG parts and sub-assemblies will survive the Mid-Earth orbit environment for the duration of the DSX spacecraft lifetime.

The appropriate coatings and finishes, based on MIL-STD-1547, will be used for VMAG.

The thermal design for VMAG does not use the spacecraft as a heat source or sink. Any heat transfer will be via the electronics unit baseplate, although some conduction via cabling cannot be avoided. The power dissipated by the VMAG electronics unit (EU) is 2.5 W, well below the 10 W limit for conducted heat transfer.

VMAG is designed to operate within specifications over the range –10° C to +40° C. VMAG is also designed to survive in the range –20° C to +50° C, but thermal regulation will not hold the VMAG to 40° C at the extremes of the survivability range, and temperature-induced effects may be present. VMAG is fully operational in the ambient environment.

The command and telemetry data to and from VMAG have already been described in Section 4.3. Assuming 20 bits per component, the VMAG data stream consists of 64 bits, including status bits. At 20 vectors per second, the VMAG data rate is 1280 bps. It is assumed that sensor and EU thermistor interface and data rates will be specified by the spacecraft or DSX contractor.

4.5. Electrical Interface

The Electrical Interface is described in the ICD. A summary of the interface is as follows:

- EU has two connectors. One for spacecraft interfaces (ECS and HSB). One for VMAG Sensor.

- Power (HSB I/F) and Signal (ECS I/F) share a single connector: 26 Contact Hi-Density D-Type Male. Manufacturer: Positronics Industries, Inc., Part #: SDD26M3P0T2.

- Sensor: 26 Contact Hi-Density D-Type Female. Manufacturer: Positronics Industries, Inc., Part #: SDD26F3P0T2.

4.6. Thermal Interface

The thermal design for VMAG does not use the spacecraft as a heat source or sink. Any heat transfer will be via the electronics unit baseplate, although some conduction via cabling cannot be avoided. The power dissipated by the VMAG electronics unit (EU) is 2.5W, well below the 10 W limit for conducted heat transfer.

VMAG is designed to operate within specifications over the range –10° C to +40° C. VMAG is also designed to survive in the range –40° C to +50° C.

Details can be found in the Thermal Analysis Memo of the CDR data package.

4.7. Materials List

VMAG does not have any Hard Magnetic Material.

See Appendix A for Table of Organic Materials List.

Metallic Materials List

All in accordance with CRD 4-9.1, and 4-9.2
Aluminum, 6061-T6 (Structure)
Electroless Nickel Plate (Finish on Chassis)
Copper (Tape)
Silver coated Copper (Braid, Bus wire)
Brass (Fasteners)
Brass, silver plated (Bifurcated terminals, Turret terminals)
Phosphor Bronze (Springs, Helicoils)
Solder 63/37
Inconel X750 (Sensor Ring)
Permalloy (Sensor Ring)
Kovar (EEE Parts)

Soft Magnetic Material List
Permalloy-Sensor Ring
Kovar-EEE Parts

4.8. Parts

The VMAG contains no pressurized systems.

All parts, materials, and processes are in accordance with MIL-STD-1543B requirements.

No toxic outgassing occurs as part of VMAG design and construction.

Parts were selected from GSFC PPL, NSPL, MIL-STD-975, or the DSX contractor's Parts Management Plan.

Class I Ozone Depleting Substances (ODS) are not used. Class II ODS and other substances requiring public notification under Federal and State laws shall be eliminated wherever possible.

UCLA has a full Hazardous Materials Program.

Electronics Parts List

Parts procurement from GSFC PPL-21 wherever possible.
Resistors – MIL-R-55342 & MIL-R-39007
Capacitors – MIL-C-55681, MIL-C-123, and MIL-C-55365
Fuses – MIL-F-23419
Connectors – MIL-C-24308, GSFC-S-311-P-4
Diodes & transistors – MIL-S-19500
Microcircuits – MIL-M-38535, Rad level R or better
RH1021-BMH-7 (internal spec equivalent to 38535)
Hybrid- spec MIL-PRF-38534
Crystal Oscillator (internal spec equivalent to 38534)
Thermistor – GSFC-S-311-P-18
Cable- NEMA-W-2500

4.9. Flight and Test Software Design

The VMAG is a "state machine" that has no programmable components when on-orbit. The command interface is kept as simple as possible to provide for robust and reliable operations. GSE for the VMAG is PC-based, and includes Ethernet connectivity for interfacing with the spacecraft electrical GSE. The telemetry is handled by the ECS.

4.10. Integration and Test

All calibration is done at UCLA using UCLA equipment. The following tests will be conducted pre-launch.

Noise Test

Overnight test in quiet environment (flux can, quiet site).

Linearity Test

Apply oscillating magnetic field; search for harmonic signal.

Zero Level Test

Reverse sensor directions in low field (flux can).

Repeat as a function of temperature.

Scale Factor Test

Apply known magnetic field; measure output.

Repeat with varying temperature.

Orthogonality Test

Apply fields along axes of magnetometer; sense orthogonal readings.

Frequency Response Test

Apply oscillating signal of varying frequency; measure amplitude and phase of output.

4.11. Documentation

VMAG will be documented to the specifications of the DSX Program Office in the following documents:

- ICD (Interface Control Document)
- PSRD (Performances Specification and Requirements Document) folded into ICD
- RVM (Requirement Verification Matrix)
- QAP (Quality Assurance Plan)

A detailed UCLA Document Tree describing all internal UCLA documentation is included in the CDR package.

4.12. Analysis

UCLA has a quality assurance plan that is consistent with ISO 9001. Appropriate controls and record keeping are used throughout the fabrication and testing processes. Such controls and record keeping apply to tools, facilities, and sensor units. GSE will also have inspection and test records.

During unit fabrication, all sub-assemblies are tested for compliance with requirements, and visually inspected for defects. Unacceptable parts are rejected. Unacceptable sub-assemblies are reworked and retested.

Any changes to designs are tested for conformity to performance specifications.

4.13. Orbital Operations

Ideally, VMAG will be deployed with power ON so that we may assess the magnetic signal of the spacecraft during boom deployment.

VMAG will transmit data within 10 seconds of ECS providing power. After 1 minute, data will meet specifications.

4.14. Data Center Requirements

The following are required for the high level processing of the data: (1) Attitude, (2) Ephemeris, and (3) EU Temperature.

5. MANAGEMENT PLAN

5.1. Roles and Responsibilities

The principal investigator, M. B. Moldwin, is responsible for the success of the DSX magnetometer fabrication and test, and is the final project arbiter. He has experience with both ground-based instrumentation as PI or co-PI of four NSF funded magnetometer arrays and space instrumentation as co-I on the ST5 magnetometer. He has extensive experience as a data analyst of magnetometer and plasma data from CRRES, ISEE 3, LANL geosynchronous, Ulysses, IMP 8 and Wind. The PI is supported by two co-investigators, Professor C. T. Russell and Dr. R. J. Strangeway, both experienced in magnetometer fabrication, test, and operation. The science team's expertise guides the design of the magnetometers, as well as designing and overseeing the calibration and trending tests. The PI is also supported by the same engineering team that built the Galileo, Polar, FAST, SACI-1 and FedSat magnetometers. The DSX/DSX magnetometer organization chart is shown in Figure 17. The space physics engineering group has prepared twenty science instruments for space flight on scientific spacecraft. The talents and experience of the personnel form an effective team for the design, development, and fabrication of scientific instruments. Collectively, the group has over 200 years of aerospace experience and significant experience in ground-magnetometer design and installation.

The project manager, J. D. Means, plans, coordinates and monitors the magnetometer design and implementation during all phases of the project. A project plan, including specific spending plan and development milestones, is used to measure performance. Project reserves and a schedule for their utilization are tied to project milestones.

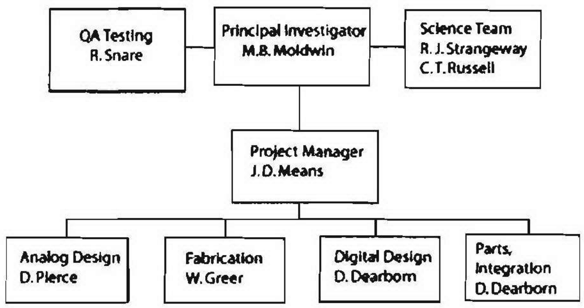

Figure 17. The DSX magnetometer organization chart.

5.2. Risk Management

The design of the DSX fluxgate has been kept simple with strong heritage from previous missions to minimize cost and schedule risk. The schedule drivers and critical path have also been identified. Schedule and cost are tracked against the project plan to identify as early as possible when project reserves are needed. Cost to completion will be tracked during fabrication and informal peer reviews held regularly.

5.3. Financial Management

The Principal Investigator is responsible for providing monthly financial reports to AFRL. These reports are generated by the personnel in the Institute of Geophysics and Planetary Physics (IGPP) business office. The IGPP business office has provided excellent

financial management for all the contracts and grants to the members of IGPP for four decades.

5.4. Project Schedule

An updated project schedule showing all major phases and major milestones is shown in Appendix B.

Schedule and Critical Milestones are as follows.

- Preliminary Design Review: February 8, 2006.

- Part Procurement: 95% complete.

-Simulator: Delivered May 1, 2006.

- GSE: Built June 1, 2006.

- Critical Design Review: June 22-23, 2006.

- Engineering Unit Delivery: October, 2006.

- Flight Unit Delivery: October, 2007.

- Launch of the AFRL DSX Spacecraft: 2009.

6. SYNOPSIS

UCLA is on schedule to deliver a vector fluxgate magnetometer that meets or exceeds the science requirements of DSX. Potential risks include those due to the late selection of the boom provider and funding uncertainty in the summer of 2006. The impact of the late selection of the boom provider is schedule since cable and I&T issues are still to be worked out. The impact of the budget delay could be catastrophic as UCLA may be forced to layoff engineering support.

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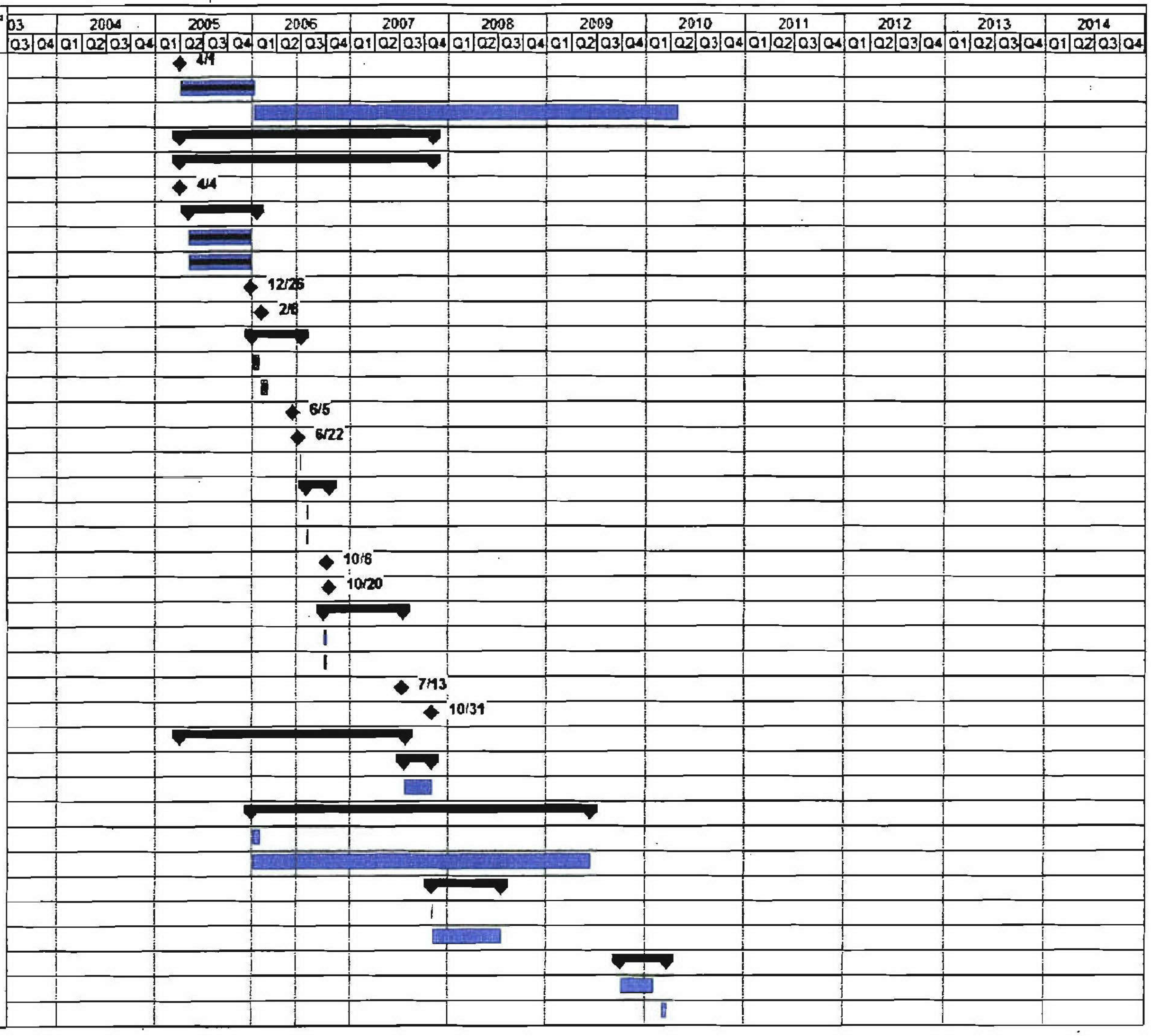
Appendix A.
Organic Materials List

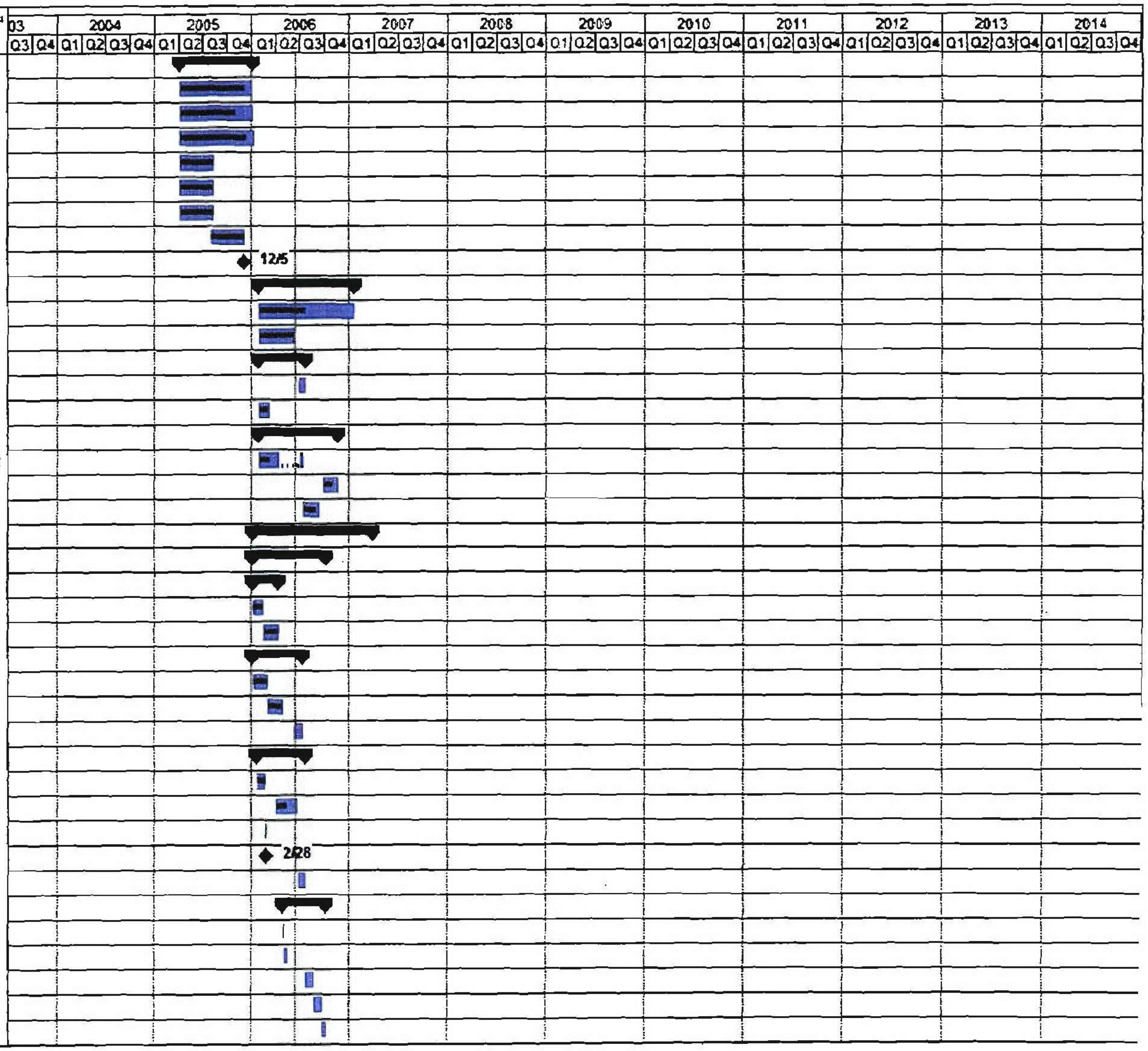
			Qualification Method	Qualification Method	Qualification Method	
Item	Organic Material	Manufacturer	TML	CVCM	W	Application
1	Lexan 9034-112 Polycarbonate	GE	0.19	0.01		Sensor Housing, Plastic Sheet
2	Scotchweld 216 B/A	MMM	0.78	0.05		Adhesive
3	CV-1142 Non-Corrosive Controlled Volatility RTV Silicone	NuSilTechnology	0.45	0.03		Adhesive/Sealant
4	MMM Tape X-1205 Kapton/Acrylic ADH/F	MMM	0.38	0.02		Tape
5	MMM Tape 850 Polyester/Acrylic ADH	MMM	0.61	0.08		Tape
6	Peek, unfilled natural 450 G Resin	Victrex	0.26	0		Sensor Housing
7	Humiseal 1B12 Acrylic	Columbia Chase	1.78	0	X	Conformal Coating
8	Humiseal 1B31 Acrylic	Columbia Chase	9.47	0.01	X	Conformal Coating
9	Laminate 85N Polymide-Thurmount	Arlon	0.84	0.01		PC Board
10	Enplate DSR green solder mask UV cured	Enthron	0.94	0.01		Mask
11	Chemglaze Z307	Specified by project				Paint
12	Lacing Tape Super Gude-Space 18 DPTH Dacron Whilte	Gudebrod	0.062	0.09		Lacing
13	Fit 350 Kynar Shrink Tubing-Neutral	Alpha Wire	0.3	0.07		Shrink Tubing

Appendix B.
Schedule

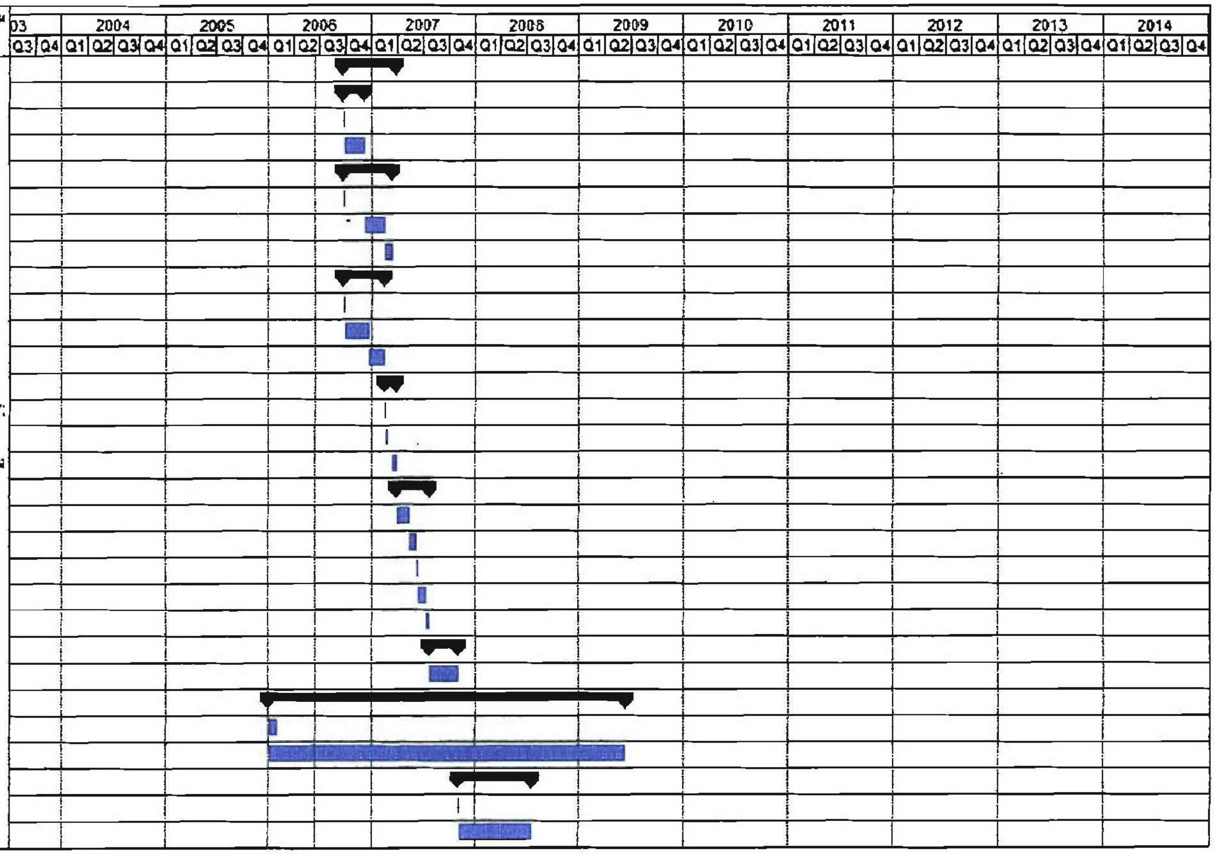
ID	Task Name	Duration	Start	Finish	Predecessors
1	Contract Award	1 day	Fri 4/1/05	Fri 4/1/05	
2	**Phase B Definitions**	198 days	Mon 4/4/05	Wed 1/4/06	1
3	**Phase C/D Equipment Fab**	225 wks	Thu 1/5/06	Tue 4/27/10	2
4	**DSX MAG Reviews/Reports/Deliveries**	**678 days**	**Mon 4/4/05**	**Tue 11/6/07**	1
5	**Reviews / Deliveries**	**678 days**	**Mon 4/4/05**	**Tue 11/6/07**	
6	Schedule Update delivery	1 day	Mon 4/4/05	Mon 4/4/05	1
7	**MAG Preliminary Design Review**	**189 days**	**Wed 5/4/05**	**Mon 1/23/06**	
8	Preliminary Mech ICD	168 days	Wed 5/4/05	Fri 12/23/05	1
9	Preliminary Elec. ICD	168 days	Wed 5/4/05	Fri 12/23/05	1
10	PDR Data Package	21 days	Mon 12/26/05	Mon 1/23/06	9
11	PDR	1 day	Wed 2/8/06	Wed 2/8/06	
12	**MAG Critical Design Review**	**130 days**	**Mon 1/2/06**	**Fri 6/30/06**	
13	Final Mech ICD	20 days	Mon 1/2/06	Fri 1/27/06	
14	Final Elec. ICD	20 days	Mon 1/30/06	Fri 2/24/06	13
15	Design Review Data Package	10 days	Mon 6/5/06	Fri 6/16/06	14
16	CDR	2 days	Thu 6/22/06	Fri 6/23/06	
17	Design Review Report	5 days	Mon 6/26/06	Fri 6/30/06	16
18	**EM Mag System / Data Package**	**65 days**	**Fri 7/21/06**	**Thu 10/19/06**	
19	EM Drawings	1 day	Fri 7/21/06	Fri 7/21/06	67
20	EM Schematics	1 day	Fri 7/21/06	Fri 7/21/06	67
21	EM Test report	10 days	Fri 10/6/06	Thu 10/19/06	73
22	EM Delivery	1 day	Fri 10/20/06	Fri 10/20/06	18
23	**PF MAG System / Data Package**	**210 days**	**Fri 9/29/06**	**Thu 7/19/07**	
24	FM Drawings	5 days	Fri 9/29/06	Thu 10/5/06	79
25	FM Schematics	5 days	Fri 9/29/06	Thu 10/5/06	79
26	FM Test report	5 days	Fri 7/13/07	Thu 7/19/07	94
27	PF Delivery	5 days	Wed 10/31/07	Tue 11/6/07	97
28	**UCLA AFRL Fluxgate**	**604 days?**	**Mon 4/4/05**	**Wed 7/25/07**	
96	**Schedule Reserve**	**70 days**	**Wed 7/25/07**	**Tue 10/30/07**	
97	Reserve	14 wks	Wed 7/25/07	Tue 10/30/07	95
98	**Spacecraft Magnetics**	**898 days?**	**Mon 1/2/06**	**Tue 6/9/09**	
99	Specifications	23 days?	Mon 1/2/06	Wed 2/1/06	
100	Testing	898 days?	Mon 1/2/06	Tue 6/9/09	
101	**DSX Instrument Integration**	**186 days?**	**Wed 10/31/07**	**Tue 7/15/08**	
102	Flight Delivery	5 days	Wed 10/31/07	Tue 11/6/07	97
103	Integration / Test	180 days?	Wed 11/7/07	Tue 7/15/08	102
104	**DSX Launch Activities**	**123 days**	**Thu 10/1/09**	**Mon 3/22/10**	
105	Delivery / Test at Launch Facilities	17.4 wks	Thu 10/1/09	Fri 1/29/10	
106	Launch	3.2 wks	Mon 3/1/10	Mon 3/22/10	



ID	Task Name	Duration	Start	Finish	Predecessors
34	**Interface Definitions**	**198 days?**	**Mon 4/4/05**	**Wed 1/4/06**	
35	Magnetic Controls	193 days	Mon 4/4/05	Wed 12/28/05	1
35	Sensor Mounting	195 days	Mon 4/4/05	Fri 12/30/05	1
37	ESU Definition	198 days	Mon 4/4/05	Wed 1/4/06	1
38	Command	90 days	Mon 4/4/05	Fri 8/5/05	1
39	Power	90 days	Mon 4/4/05	Fri 8/5/05	1
40	Data	90 days	Mon 4/4/05	Fri 8/5/05	1
41	Interface Verification Unit	90 days	Mon 8/1/05	Fri 12/2/05	
42	IVU Delivery	1 day?	Mon 12/5/05	Mon 12/5/05	41
43	**Component Procurement**	**260 days**	**Wed 1/25/06**	**Mon 1/22/07**	
44	Flight Components	52 wks	Wed 1/25/06	Mon 1/22/07	30,2
45	Engineering/Commercial Comp	20 wks	Wed 1/25/06	Tue 6/13/06	30,2
46	**GSE Mag stimulus**	**129 days**	**Wed 1/25/06**	**Fri 7/21/06**	
47	Stimulus coil design/fab	21 days	Mon 6/26/06	Fri 7/21/06	2,31
48	Power supply Procurement	6 wks	Wed 1/25/06	Tue 3/7/06	30,2
49	**Ground Hardware Dsn/Fab**	**215 days**	**Wed 1/25/06**	**Mon 11/20/06**	
50	GSE Test Hardware	65 days	Wed 1/25/06	Fri 7/14/06	39,40,30,2
51	Engineering Test Sftwr	40 days	Tue 9/26/06	Mon 11/20/06	56,59,50
52	Software Dev Hdwr	44 days	Sat 7/15/06	Wed 9/13/06	50
53	**DSX Mag Hardware Fab**	**322 days**	**Thu 1/5/06**	**Thu 3/29/07**	
54	**Engineering Mag EU**	**197 days**	**Thu 1/5/06**	**Thu 10/5/06**	
55	**Engr. Fluxgate/ADC**	**70 days**	**Thu 1/5/06**	**Wed 4/12/06**	
56	Circuit Design	6 wks	Thu 1/5/06	Wed 2/15/06	1,34
57	PC Board Layout	8 wks	Thu 2/16/06	Wed 4/12/06	56,10
58	**Engr. Digital s/c interface**	**134 days**	**Thu 1/5/06**	**Tue 7/11/06**	
59	Circuit Design	8 wks	Thu 1/5/06	Wed 3/1/06	1,34
60	PC Board Layout/Mfg.	8 wks	Thu 3/2/06	Wed 4/26/06	59,10
61	PC Board Assy/test	4 wks	Wed 6/14/06	Tue 7/11/06	60,45
62	**Engr. Mag-SU**	**129 days**	**Tue 1/24/06**	**Thu 7/20/06**	
63	Design	4 wks	Tue 1/24/06	Mon 2/20/06	10,1,36
64	Component Mfg.	12 wks	Mon 4/3/06	Fri 6/23/06	63
65	Drill Template Mfg.	5 days	Tue 2/21/06	Mon 2/27/06	63
66	Drill Template Delivery	1 day	Tue 2/28/06	Tue 2/28/06	1,13,65
67	Sensor Assy/test	4 wks	Mon 6/26/06	Thu 7/20/06	64
68	**Engr. mag Assy/Test**	**117 days**	**Thu 4/27/06**	**Thu 10/5/06**	
69	Wiring Harness design	5 days	Thu 4/27/06	Wed 5/3/06	57,60
70	Wiring Harness Fab	2 wks	Thu 5/4/06	Wed 5/17/06	69
71	System Assy	5 wks	Fri 7/21/06	Thu 8/24/06	70,67,61
72	System Initial Test	4 wks	Fri 8/25/06	Thu 9/21/06	71
73	System Test	2 wks	Fri 9/22/06	Thu 10/5/06	72



ID	Task Name	Duration	Start	Finish	Predecessors
74	**Flight Mag EU**	**135 days**	**Fri 9/22/06**	**Thu 3/29/07**	
75	**Flight Fluxgate/ADC**	**55 days**	**Fri 9/22/06**	**Thu 12/7/06**	
76	Circuit Modification	1 wk	Fri 9/22/06	Thu 9/28/06	72
77	PC Board Layout/Mfg	10 wks	Fri 9/29/06	Thu 12/7/06	76
78	**Flight Digital**	**125 days**	**Fri 9/22/06**	**Thu 3/15/07**	
79	Circuit Modifications	1 wk	Fri 9/22/06	Thu 9/28/06	72
80	PC Board Layout/Mfg.	10 wks	Fri 12/8/06	Thu 2/15/07	79,77
81	PC Board Assy/test	4 wks	Fri 2/16/07	Thu 3/15/07	80,44
82	**Flight Mag-SU**	**105 days**	**Fri 9/22/06**	**Thu 2/15/07**	
83	Design Modifications	1 wk	Fri 9/22/06	Thu 9/28/06	72
84	Component Mfg.	12 wks	Fri 9/29/06	Thu 12/21/06	83
85	Sensor Assy/test	8 wks	Fri 12/22/06	Thu 2/15/07	84
86	**Flt. Mag Assy/Test**	**30 days**	**Fri 2/16/07**	**Thu 3/29/07**	
87	Wiring Harness design	1 day	Fri 2/16/07	Fri 2/16/07	76,79,85,7
88	Wiring Harness Fab	1 wk	Mon 2/19/07	Fri 2/23/07	87
89	System Assy	2 wks	Fri 3/16/07	Thu 3/29/07	75,78,62,8
90	**Flight Testing/Tuning**	**83 days**	**Fri 3/30/07**	**Tue 7/24/07**	
91	Calibration	6 wks	Fri 3/30/07	Thu 5/10/07	89
92	Conformal Coat / Final Assy	4 wks	Fri 5/11/07	Thu 6/7/07	91
93	Vibration	5 days	Fri 6/8/07	Thu 6/14/07	92
94	Thermal Vacuum #1	4 wks	Fri 6/15/07	Thu 7/12/07	93
95	Data Package Preparation	8 days	Fri 7/13/07	Tue 7/24/07	94
96	**Schedule Reserve**	**70 days**	**Wed 7/25/07**	**Tue 10/30/07**	
97	Reserve	14 wks	Wed 7/25/07	Tue 10/30/07	95
98	**Spacecraft Magnetics**	**898 days?**	**Mon 1/2/06**	**Tue 6/9/09**	
99	Specifications	23 days?	Mon 1/2/06	Wed 2/1/06	
100	Testing	898 days?	Mon 1/2/06	Tue 6/9/09	
101	**DSX Instrument Integration**	**185 days?**	**Wed 10/31/07**	**Tue 7/15/08**	
102	Flight Delivery	5 days	Wed 10/31/07	Tue 11/6/07	97
103	Integration / Test	180 days?	Wed 11/7/07	Tue 7/15/08	102



Acronyms

A/D	analog to digital
ADC	analog to digital converter
AFGL	Air Force Geophysics Laboratory
ATS	Applications Technology Satellite
CCE	Charge Composition Explorer
CVCM	Collected Volatile Condensable Material
CY	Calender Year
DOC	Department of Commerce
DOD	Department of Defense
DSRD	Draft Sensor Requirements Document
EDR	Environemental Data Record
EDU	Engineering Development Unit
EMC	Electromagnetic Compatability
EMI	Electromagnetic Interference
EU	Engineering Unit
FAC	Field-Aligned Current
FAST	Fast Auroral Snapshot Explorer
FedSat	Federation Satellite (Australia)
FPGA	Field Programmable Gate Array
FU	Flight Unit
FY	Fiscal Year
GMR	Gross Magnetoresistive Resistor
GPS	Global Positioning Satellite
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
I&T	Integration and Test
ICD	Interface Control Document
IGPP	Institute of Geophysics and Planetary Physics
IMF	Interplanetary Magnetic Field
IPO	Integrated Program Office
ISEE	International Sun-Earth Explorer
ISO	International Standardization Organization
ITAR	International Traffic in Arms Regulations
JPL	Jet Propulsion Laboratory
LSB	Least Significant Bit
MEASURE	Magnetometers Along the Eastern Atlantic Seaboard for Undergraduate Research and Education
MEO	Medium-Earth Orbit
NASA	National Aeronautics and Space Administration
DSX	Air Force Research Lab/Medium-Earth Orbit Satellite
NOAA	National Oceanic and Atmospheric Administration
NPSL	NASA Parts Selection List
OGO	Orbiting Geophysical Observatory
PC	Personal Computer
PCAD	Personal Computer Aided Design
PDE	Principal Design Engineer
PET	Principal Electronic Technician

PF	Protoflight
PI	Principal Investigator
PPL	Preferred Parts List
PVO	Pioneer Venus Orbiter
QA	Quality Assurance
RDR	Raw Data Records
RF	Radio Frequency
RMS	Root mean square
SACI-1	Satélite de Aplicações Cientificas
SCATHA	Spacecraft charging at high altitude
SDE	Senior Development Engineer
DSX	Space Environment Sensor Suite
SMALL	Sino Magnetic Array at Low Latitudes
SRD	Sensor Requirements Document
ST5	Space Technology 5
TID	Total Integrated Dose
TBS	To be Specified
TML	Total Mass Loss
UCLA	University of California Los Angeles
UCOP	University of California Office of the President
VMAG	Vector Magnetometer
WMM	World Magnetic Model